The UK climate change levy and potential for double-dividend effects under different labour market specifications: a computable general equilibrium analysis for the United Kingdom

Grant Jordan Allan[a], Peter McGregor[a,b], Kim Swales[a,b] and Karen Turner[a]

[a] Fraser of Allander Institute and Department of Economics, University of Strathclyde
[b] Centre for Public Policy for Regions, Universities of Glasgow and Strathclyde

Paper submitted for ECOMOD Conference, Moscow, 11th-12th September 2007
May 2007
Draft version – do not cite

Acknowledgements

The authors gratefully acknowledge the support of the Engineering and Physical Science Research Council (grant reference GR/S26958/01) through the SuperGen Marine Energy Research Consortium. CPPR is a joint research institute of the Universities of Glasgow and Strathclyde funded by the Scottish Funding Council.

1. Introduction

There has been a growing tendency for governments to tax energy use in order to reduce emissions from pollution generating activities. Since Pigou (1938), the economic's literature has discussed how socially desirable outcomes can be achieved by internalising environmental externalities through taxation. Further, the political economy energy/economic literature has acknowledged that environmental and distortionary taxes can "interact" (Goulder, 1995), and that taxes might be reformed – swapping the burden of the taxation from taxing "bads" to subsidising "goods" (Bosquet, 2000).

The debate in the double-dividend literature (Pearce, 1991; Goulder, 1995) attempts to concern the conditions under which "swaps of environmental taxes for distortionary taxes may produce a double divided by not only discouraging environmental damaging activities but also reducing the distortionary costs of the tax system" (Goulder, 1995). As Takeda (2006) points out, a potential double dividend means that emissions regulations can be introduced without any additional burden. This has unsurprisingly thus attracted the attention of policymakers, and also considerable academic research into both its theoretical and empirical basis (Takeda, 2006).

Goulder (1995, p159) distinguishes three variants of the double dividend hypothesis – the weak, intermediate and strong forms – which all say something about the interaction between environmental taxes and distortionary taxation and differ "in terms of what they propose about the costs of revenue neutral environmental tax policies". In this paper, we follow Bosquet (2000, p20) in interpreting the double dividend as "an environmental improvement coupled with an economic benefit: revenues of environmental taxes could be used to cut distorting taxes on capital and labour and thus reduce the excess burden of the tax system". Manresa and Sancho (2005) identify an "employment double dividend" - the introduction of a budget neutral increase in taxation revenues from environmental taxation alongside an equal gross cost in taxes on labour – which results in a higher level of employment.

A number of CGE studies have analysed the system-wide effects of energy taxation (Semboja, 1994; Scrimgeour *et al*., 2005; Wissema and Dellink, 2006). Others have attempted to model both the raising of energy/environmental taxation, and the simultaneous recycling of this revenue through a number of routes. In this paper, we note that there is a large collection of recent CGE papers that have explored the impacts of the introduction of an energy tax and an additional revenue-offsetting cut in taxation on labour (Carraro et al., 1996; Felder and Nieuwkoop, 1996[1]; Bosello and Carraro, 1998[2]; Kemfert and Welsch, 2000[3]; Parry and Bento, 2000; Pench, 2001[4]; Boyd and Ibarrarán, 2002[5]; Manresa and Sancho, 2005[6]; Takeda, 2006).

Some of these have found support for a possible double-dividend (Felder and Nieuwkoop, 1996[7]; Parry and Bento, 2000; Manresa and Sancho, 2005) and others have found no evidence (Boyd and Ibarrarán, 2002) or a mixed response (Carraro *et al*., 1996; Bosello and Carraro, 1998[8]; Kemfert and Welsch, 2000[9]; Pench, 2001; Takeda, 2006[10]). (See Patuelli *et al*., (2005) for a meta-analysis of recent simulation studies of environmental tax reform).

It has been noted however that the assumed structure of the labour market will have important consequences for the impact of the labour-taxation reduction element of the package. Manresa and Sancho (2005) examine two alternative extreme

---

[1] Felder and Nieukoop (1996) consider recycling additional revenues to government from an energy tax through lump-sum transfers and low and high reductions in marginal income tax rates.
[2] Bosello and Carraro (1998) introduce a CO_2 emission tax and recycle revenue through lowering social security contributions paid by employers.
[3] Kemfert and Welsh (2000) consider labour cost reduction alongside lump-sum transfers to households as alterative ways of recycling revenue from a carbon tax.
[4] Pench (2001) considers four alternative scenarios in which public expenditure remains constant while raising taxes on 1) the output of the energy sector and 2) final demand of energy products, and recycling these revenues through 3) personal income tax rates and 4) social security contributions.
[5] Boyd and Ibarrarán (2002) maintain the same value of total tax revenues by lowering the tax rates on capital and labour in equal proportion.
[6] Payroll taxes are lowered to maintain the neutral effect on government revenues in Menresa and Sancho (2005).
[7] Felder and Nieuwkoop (1996, p247) "confirm that double-dividend hypothesis that environmental tax reforms not only enhance environmental quality but also lower the excess burden imposed on the economy from taxation".
[8] Bosello and Carraro (1998) find a short-run employment double-dividend, but this benefit is smaller in the long run.
[9] Kemfert and Welsch (2000) report higher employment, GDP and lower CO2 emissions under the case where carbon tax revenues are recycled through labour cost reduction, but not through lump sum transfers.
[10] Takeda (2006) finds support for the weak double dividend in all scenarios, however the strong double dividend (Goulder, 1995) only arises when taxes on capital, and not labour, are reduced.

specifications of the national labour market. In their “rigid” version, labour supply is totally inelastic, while in their “flexible” version the representative consumer “offers all labour elastically at the going real wage up to the point of use depletion” (Manresa and Sancho, 2005). They suggest that “’flexibility in the labour market is a desirable property for an economy to have in order to improve its chances to achieve a double dividend” (Manresa and Sancho, 2005, p. 1583).

We attempt to explore an element of the double dividend hypothesis using a CGE modelling framework parameterised on UK data (UKENVI) to test the economic (including employment), energy and environmental implications of reductions in the rate of social security contributions paid by employers. This is an integral component of the UK government’s Climate Change Levy (CCL) package, which was first introduced in 2001. In its most basic interpretation, it is designed to increase taxation on energy use while making revenue-neutral reductions in the taxation of labour through lowering the employers’ social security contributions. We aim to test the economic and environmental impacts of this policy under three different configurations of the UK labour market.

The CCL is an example of the trend towards “green” taxation in the UK – following the Marshall report to the 1998 Budget – which has been discernable across developed countries since the early 1990s and is associated with a systematic movement of the tax burden away from labour and capital and towards natural resource use. (See Ekins (1999) and Bosquet (2000) for reviews).

Section 2 briefly outlines the CCL, and sets out the theoretical implications of a reduction in employers’ social security contributions in a general equilibrium system. Section 3 describes the UKENVI model. Section 4 reports preliminary results from modelling the reduction in social security contributions under a variety of different labour market specifications. Section 5 briefly concludes and offers directions for future research.

2. The climate change levy – description and analysis

2.1 The UK's climate change levy package

The UK Government's Budget of 2001 (HM Treasury, 2001), states "The CCL is designed to encourage the non-domestic sector to become more energy efficiency and so reduce carbon emissions". Specifically, the aim is to deliver the expected reduction of at least 5 million tonnes of carbon by 2010, "while protecting the competitiveness of UK firms" (HM Treasury, 2001) by not increasing the tax burden from industry as a whole, so that there is no net gain in the public finances.

The CCL was introduced on 1st April 2001 (2 years after it was first announced) and applies to energy-use in non-domestic and non-transport industry, commercial and public sectors (Varma, 2003). Individual rates of levy (shown in Table 1), which were frozen in the 2002 Budget, apply to physical amounts of gas, solid fuel (coal), electricity and LPG usage and are applied to energy bills before VAT. The CCL does not apply to oils, which are already subject to excise duty. It does not apply to the domestic or transport sector "to avoid increasing fuel poverty and to encourage a more sustainable transport system" (HM Treasury, 2001). Nor does it apply to "energy that is an input to the production of another energy product" (Varma, 2003) (e.g. electricity generation – because energy *use* is taxed)[11]. It also doesn't apply to energy purchased by registered charities for non-business use.

[Table 1 here]

There are a number of further exemptions. In particular, electricity generated from renewable sources, (e.g. solar, wind and marine power) is not subject to the levy. In the 2002 Budget, electricity generated using coalmine methane (CMM) and in combined heat and power (CHP) plants were added to the exempt category. However, these two additions will be reviewed in light of further information on the environmental benefits of the former, and on changes in energy prices in the latter,

[11] This would exclude, for instance, the use of "gas and coal to produce electricity, coal used to make coke, electricity used for pumping water into high level reservoirs in pumped storage hydro-electric stations and energy used to crack crude oil in the oil refining process" (Varma, 2003, p53).

over the next few years. There are other exemptions, mainly applying to activities that fall under specific schemes or types of industrial processes, and, in the case of the horticulture activities, special measures are applied in line with what has been done in other countries[12]. Further, as Ekins and Etheridge (2006) explain, energy intensive sectors were allowed to negotiate discounts in the rate of tax charged under the CCL in exchange for agreeing Climate Change Agreements (CCAs) targeting energy use or carbon emissions at the sectoral level. Forty-four sectors[13] agreed an 80% discount in the initial rate of the CCL charged, subject to meeting the sectors targets, set for two year intervals. If the target was not met, the full rate of CCL would be payable over the next two years.[14]

The CCL package embodies the concept of overall *ex ante* revenue-neutrality, so that the total of firms' costs are expected to be unaffected by its introduction. As outlined above, the CCL involves a tax on businesses' use of energy. However, on the cost offsetting side, CCL offers a complex set of distinct policy instruments. First, incorporated into CCL is a reduction in employers' national insurance contributions of 0.3%. Second, there is modest expenditure to support energy efficiency measures, and firms in the sectors regulated by the EU's integrated Pollution Prevention and Control Directive (IPPC) (which covers energy-intensive sectors) are eligible to negotiate an 80% discount on the levy in return for commitments to significant improvements in energy efficiency. Third, there are enhanced capital allowances for investment in energy efficiency.

2.2 Theoretical analysis of impact of NI subsidy

Here we focus on one of the two biggest elements of the CCL package – namely the cut of 0.3% in national insurance contributions paid by the employer. The revenue-neutrality of the complete CCL package is assumed *ex ante*. The anticipated £1 billion (Bond *et al*., 2001) revenues from the energy taxation element are expected

[12] "The UK horticulture sector is relatively energy-intensive and has a large number of small companies and is exposed to significant international competition" (Varma, 2003)
[13] This fell to 42 by the time of the second milestone assessment due to 'Reprotech' and 'Vehicle Builders and Repairers' sectors ending these agreements in the interim.
[14] FES (2005) records that at the end of the second milestone assessment (2004), 38 out of 42 sectors had their CCL discounts renewed for the next two years. Four sectors didn't submit any information at the end of their second assessment, and so had their CCA terminated.

to be accounted for by the 0.3% cut in employers' national insurance contributions and the other expenditure components of the CCL package[15]. It is appropriate to consider the National Insurance component individually since this will have quite different effects that the tax on energy use, which is the other major element of the CCL[16] In the longer term, the government may adjust employment taxes to ensure overall revenue-neutrality and so render the employers' national tax rate effectively endogenous, and we intend to explore this in further work. In essence, ex ante revenue-neutrality only holds at the level of the UK as a whole.

Varma (2003) is, to our knowledge, one of the first attempts to provide an analysis of the Climate Change Levy (CCL) and so provides a useful reference point for our own research. Essentially, we extend Varma's (2003) analysis in a number of respects. First, we provide an explicitly general equilibrium analysis of the National Insurance (NI) component of the CCL, whereas Varma's (2003) paper is essentially partial equilibrium in nature (although general equilibrium effects are alluded to). We would expect the CCL to generate important system-wide effects, and these can only be captured by the use of appropriate theoretical (and empirical) models. Secondly, we provide a more comprehensive theoretical analysis.

Varma (2003) concentrates on the energy tax elements of the CCL, but provides no detailed analysis of the likely impact of the cut in NI contributions associated with revenue recycling (although the existence of such effects is, of course, acknowledged). This is a crucial aspect of the CCL and the major mechanism through with the overall intended revenue-neutrality of the tax is secured. Finally, while Varma (2003) contains no original estimates of the effects of the CCL, we provide what we believe will be the first computable general equilibrium analysis of the likely economic impact of the NI component of the CCL package using our CGE model of the UK economy.

The likely impact of the cut in employers' NI contributions is similar in its impact to the introduction of a labour subsidy – see Harrigan *et al*. (1996) for an

[15] Bond *et al*. (2001) notes that the original form of the CCL was intended to raise £1.75bn per annum, with employers' NI contributions being lowered by 0.5 percentage points.
[16] Studying the impact of the energy taxation element of the CCL will be an important part of our future work in this area.

extensive theoretical and empirical analysis of the general equilibrium impacts of a labour subsidy on a *regional* economy using an earlier version of the AMOS modelling framework. We extend this analysis in the present case in two ways - we use multi-period simulations to examine the dynamics of the process, as well as the short-run and long-run impacts, plus we track the resultant impacts on a set of linked environmental and energy indicators.

We now sketch the likely aggregate labour market effects of the change in the national insurance contributions (a reduction in the tax on labour supply). First, this change will lower the employer cost of labour, shifting the wage curve downwards. This is reinforced by the presence, in this case, of a stimulus to aggregate demand through the increased level of government expenditure through the NI reduction (note: we don't assume that the reduction in NI revenue is offset by a reduction elsewhere in government expenditure). The decrease in the price of labour leads to a substitution in favour of labour and away from capital. In the short run, employment and wage rates will increase. In the long run, capital accumulates until rental rates again equal the user cost of capital.

Figure 1 illustrates the likely impacts. The national labour market is represented by a bargained real wage (BRW_0) curve, reflecting the presence of some degree of national labour market wage flexibility, and the general equilibrium (GE) demand for labour (D_0). We are initially assumed to be at point A in equilibrium. The cut in the rate of employment taxation results in a decrease in the cost of labour to the employer, thereby shifting the GE wage curve down (BRW_1). Further, the stimulus to labour demand from the unconstrained fiscal expenditure shifts the GE demand curve for labour outwards (D_1). Depending on the scale of each effect, the new equilibrium could be at a lower real cost of employment to the firm (e.g. point B). on the increases the real wage rate and the employment rate.

Under an exogenous labour supply closure, however – shown by the ELS curve - we assume a perfectly inelastic labour supply constraint at the initial equilibrium. Under this setting, the decrease in the rate of national insurance will not change the supply of labour (this is fixed), but the new labour demand schedule will would be expected to increase the real cost of employment to the firm. The resultant equilibrium would be at point C. The third labour market option is that of a fixed real wage rate – shown in Figure 1 as RWR_0. Following the cut in the rate of national insurance, this lowers the RWR employment schedule (to RWR_1). The increase in the labour demand from the fiscal stimulus results in a new equilibrium at point D. The interesting question is, as well as these expected effects upon the labour market, what will be the impact on emissions and energy use following the cut in the rate of taxation upon labour?

[Figure 1 here]

Of course, the resultant employment effects will vary across the industrial sectors, this time depending on the labour intensity of the production process. *Ceteris paribus*, the more labour intensive the sector the greater the stimulus to the demand for labour, and the greater the beneficial employment effects.

3. UKENVI model description

CGE models are now extensively used in studies of the energy-economy-environment nexus at the national and regional levels (see Allan et *al*., 2006). The popularity of CGEs in this context reflects their multisectoral nature combined with their fully specified supply-side, facilitating the analysis of economic, energy and environmental policies. Here we employ UKENVI, a CGE modelling framework parameterised on UK data. Full details on UKENVI are given in (Allan *et al*., 2006).

3.1 Structure

UKENVI has three transactor groups, namely households, corporations and government; 25 commodities and activities, 5 of which are energy commodities/supply and one exogenous external transactor (rest of the world (ROW)).[17] Throughout this paper commodity markets are taken to be competitive. We do not explicitly model financial flows.

[17] The sectoral breakdown is given in Appendix 1 and a condensed version of the UKENVI model is given in Appendix 2.

The UKENVI framework allows a high degree of flexibility in the choice of key parameter values and model closures. However, a crucial characteristic of the model is that, no matter how it is configured, we impose cost minimisation in production with multi-level production functions (see Figure 2). There are four major components of final demand: consumption, investment, government expenditure and exports. Of these, real government expenditure is taken to be exogenous. Consumption is a linear homogenous function of real disposable income. Exports (and imports) are generally determined via an Armington link and are therefore relative-price sensitive (Armington, 1969).

The separation of different types of energy and non-energy inputs in the intermediates block is in line with the general 'KLEM' (capital-labour-energy-materials) approach that is most commonly adopted in the literature. There is currently no consensus on precisely where in the production structure energy should be introduced, for example, within the primary inputs nest, most commonly combining with capital (e.g. Bergman, 1988; Bergman, 1990), or within the intermediates nest (e.g. Beausejour *et al*., 1994). Given that energy is a produced input, it seems most natural to position it with the other intermediates, and this is the approach we adopt here. However, any particular placing of the energy input in a nested production function restricts the nature of the substitution possibilities between other inputs. The empirical importance of this choice is an issue that requires more detailed research.

The multi-level production functions in Figure 2 are generally of constant elasticity of substitution (CES) form, so there is input substitution in response to relative price changes, but with Leontief and Cobb-Douglas available as special cases. In the applications reported below, Leontief functions are specified at two levels of the hierarchy in each sector – the production of the non-oil composite and the non-energy composite – because of the presence of zeros in the base year data on some inputs within these composites. CES functions are specified at all other levels.

We parameterise the model to be in long-run equilibrium in the base-year period. This implies that the capital stock in each industrial sector is initially fully adjusted to its desired level. There are no vintage effects in the model. In this paper we give simulation results for two alternative conceptual time periods – the short run and the long run – and in a period-by period setting. In the short-run, the capital stock is fixed, both in terms of its absolute size and in its distribution to individual sectors, although labour can move freely between sectors in this time interval. In the long run, capital stock in each sector readjusts to its new desired level, given the new values for sectoral value added, the user cost of capital and the wage rate. We assume that interest rates are fixed in international capital market, so that the user cost of capital varies with the price of capital goods.

Where we run the model in a period-by-period mode with a gradual updating of capital stocks, a close adjustment to the long-run values will often take over 25 years. If the model is run in this mode, each sector's capital stock is updated between periods via a simple capital stock adjustment procedure, according to which investment equals depreciation plus some fraction of the gap between the desired and actual capital stock.[18] This treatment is wholly consistent with sectoral investment being determined by the relationship between the capital rental rate and the user cost of capital. The capital rate is the rental that would have to be paid in a competitive market for the (sector specific) physical capital: the user cost is the total cost to the firm of employing a unit of capital. Where the rental rate exceeds the user cost, desired capital stock is greater than the actual capital stock and there is therefore an incentive to undertake net capital investment. The resultant capital accumulation puts downward pressure on rental rates and so tends to restore equilibrium. In the long-run the capital rental rate equals the user cost in each sector, and the risk-adjusted rate of return is equalised between sectors.

The important focus in this paper is on the nature of the specification of the labour market. We impose a single UK labour market characterised by perfect sectoral mobility. In our first specification, wages are determined via a bargained real wage function in which the real consumption wage is directly related to workers' bargaining power, and therefore inversely to the unemployment rate (Blanchflower and Oswald, 1994; Minford et al., 1994). Here, we parameterise the bargaining function from the econometric work reported by Layard et al. (1991):

[18] This process of capital accumulation is compatible with a simple theory of optimal investment behaviour given the assumption of quadratic adjustment costs.

(1) $$w_t = \alpha - 0.068u + 0.40w_{t-1}$$

Where: w and u are the natural logarithms of the UK real consumption wage and the unemployment rate respectively, t is the time subscript and α is a parameter which is calibrated so as to replicate equilibrium in the base period.[19] The second specification is an exogenous labour supply closure, which, in effect, implies a completely wage-inelastic aggregate labour supply function. This is quite a common labour market closure in national CGE models, but is clearly a limiting case. In this closure, the real wage adjusts continuously to ensure equality of aggregate labour demand and the fixed aggregate labour supply. Nonetheless it is a useful benchmark. Thirdly, as an alternative limiting case (as in Manresa and Sancho, 2005), we incorporate a real wage resistance closure, in which the real consumption wage is fixed and total employment changes to ensure labour market equilibrium. In effect, labour supply is infinitely elastic (over the relevant range) at the prevailing real wage rate. The results from these three alternative treatments of the labour market are detailed in Section 4.

3.2 Database

The main database for UKENVI is a specially constructed Social Accounting Matrix (SAM) for the UK economy for the year 2000. This required the initial construction of an appropriate UK Input-Output (IO) table since an official UK analytical table has not been published for any year since 1995. A twenty-five sector SAM, built on the basis of single-entry bookkeeping (Allan *et al*., 2006), was then developed for the UK using the IO table as a major input. The sectoral aggregation is chosen to focus on energy sectors. The division of the electricity sector between renewable and non-renewable generation used an experimental disaggregation provided for Scotland. This was then adjusted to reflect the different pattern of electricity generation between the UK and Scotland. Five sets of income-expenditure accounts were constructed for households, corporations, government, capital and the

[19] The calibrated parameter plays no part in determining the sensitivity of the endogenous variables to exogenous disturbances, but the initial assumption of equilibrium is an important assumption.

external sector (rest of the world). Full details of the construction of the UK IO table and SAM are provided in Allan *et al*., (2006).

The structural characteristics of the UKENVI model are parameterised on the UK SAM for 2000. In all sectors, the elasticity of substitution at all points in the multi-level production function takes the value of 0.3, apart from where Leontief functions have been imposed. The Armington trade elasticities for imports and exports are 2.0 for all other sectors.

3.4 Simulation strategy

In simulating the recycling element of the CCL, we reduce the rate of national insurance paid by employers by 0.3%, across all sectors in the UK economy. This is a step change in the rate of national insurance, which remains into the future. We report results in Section 4 below for two conceptual time periods, the short- and long-run, as well as running the UKENVI model in the period-by-period setting to trace the dynamics of the path to the new long run equilibrium. All simulations are compared to a counterfactual in which the long-run equilibrium position recreates itself, i.e. if the model is run forward without any disturbances it will recreate the base year values.

4. Preliminary results and discussions

Table 2 shows preliminary aggregate economic results for the short and long run time periods for a 0.3% reduction in the rate of social security contribution paid by employers. Under the bargaining labour market specification, we see a small positive change in employment and the real consumption wage in the short and long run. There are small reductions in the unemployment rate in both time-periods. The exogenous labour supply specification is shown in the next two columns, where there is no employment change in either time period. Real wages are increased in this simulation by a larger amount than under the bargaining closure, as expected. Employment, and the unemployment rate, remains fixed by definition. There is zero change in Gross Domestic Product (GDP) under this configuration of the labour market. In the real wage resistance case, there are short run and long run gains to GDP.

[Table 2 here]

The dynamic paths of the movement to the long run equilibrium results can also be traced by running the UKENVI model in its period-by-period setting as detailed in Section 3.1 above. The time paths for GDP, employment and CO_2 emissions are shown in Figure 3, Figure 4 and Figure 5 respectively.

[Figure 3 here]

[Figure 4 here]

[Figure 5 here]

The time paths for GDP reveal that in the long-run, the difference in GDP and employment under the bargaining labour market assumption is around £100 million per year, and with additional employment of almost 4 thousand FTE jobs per year. This is around a fifth of the scale of the GDP impact compared to the real wage resistance setting, and a quarter the size of the absolute employment effects per year in this specification of the labour market. Under the exogenous labour supply specification, there is a very small negative impact on GDP (around £1.7 million loss in the long run).

The estimated CO_2 impacts are interesting. The decrease in NI contributions result in increases in CO_2 generation under both the bargaining and real wage resistance setup, while in the exogenous labour supply specification, CO_2 emission are lower by around 10,000 tonnes per year.

These results appear to confirm the suggestion of Manresa and Sancho (2005) that the structure of the labour market will be important for the possibility that double-dividend effect might result from a revenue neutral switching of taxation from taxation of energy to subsidising labour costs. Clearly, future work is required to understand the mechanisms at work over the CCL package as a whole, especially modelling the energy taxation side. Where the package has such high aims for both economic and environmental benefits, it is perhaps prudent to examine individually the two main elements of the package, before these are brought together. It is hoped that understanding the revenue-recycling element of the CCL package will help to inform the evaluation of the package as a whole.

References

Allan, G.J., Hanley, N.D., McGregor, P.G., Swales, J.K. and Turner, K.R. (2006), "The macroeconomic rebound effect and the UK economy", Final report to DEFRA, May 2006.

Armington, P. (1969), "A theory of demand for products distinguished by place of production", IMF Staff Papers 1969, 16, p. 157-178.

Beausejour, L., Lenjosek, G and Smart, M. (1994), "A CGE approach to modelling carbon dioxide emissions control in Canada and the United States", The World Economy, 18, p. 457-489.

Bergman, L. (1988), "Energy policy modelling: a survey of general equilibrium approaches", Journal of Policy Modelling, 10(3), p. 377-399.

Bergman, L. (1990), "Energy and environmental constraints on growth: a CGE modelling approach", Journal of Policy Modelling, 12, p. 671-691.

Blanchflower, D.G. and Oswald, A.J. (1994), *The Wage Curve*, M.I.T. Press, Cambridge, Massachusetts.

Bond, S., Klemm, A. and Simpson, H. (2001), "Labour and Business Taxes", The Institute for Fiscal Studies, IFS Election Briefing Note No. 6, May 2001

Bosello, F. and Carraro, C. (1998), "Recycling energy taxes: impacts on a disaggregated labour market", Paper presented at the FEEM-IDEI-INRA conference, 14th-15th June 1998.

Bosquet, B. (2000), "Environmental tax reform: does it work? A survey of the empirical evidence", Ecological Economics, 34, p. 19-32.

Boyd, R. and Ibarrarán, M.E. (2002), "Costs of compliance with the Kyoto Protocol: a developing country perspective", Energy Economics, 24, p. 21-39.

Carraro, C., Galeotti, M. and Gallo, M. (1996), “Environmental taxation and unemployment: Some evidence on the ‘double dividend hypothesis’ in Europe”, Journal of Public Economics, 62, p. 141-181.

Ekins P. (1999), “European environmental taxes and charges: recent experience, issues and trends”, Ecological Economics, 31, p. 39-62.

Ekins, P. and Etheridge, B. (2006), “The environmental and economic impacts of the UK climate change agreements”, Energy Policy, 34, p. 2071-2086.

Felder, S. and Nieuwkoop, R, v. (1996), “Revenue recycling of a CO2 tax: Results from a general equilibrium model for Switzerland”, Annals of Operation Research, 86, p. 233-265.

Future Energy Solutions (2005), “Climate change agreements – results of the Second target period assessment”, Report to DEFRA, July 2005

Goulder, L.H. (1995), “Environmental taxation and the double dividend: a reader’s guide”, International Tax and Public Finance, 2, p. 157-183

Harrigan, F., McGregor, P.G. and Swales, J.K. (1996), “The system-wide impact on the recipient region of a regional labour subsidy”, Oxford Economic Papers, 48, p. 105-133.

HM Treasury (2001), “Budget Report 2001, Chapter 6: Protecting the environment”, available online at http://www.hm-treasury.gov.uk/budget/budget_2001/budget_report/bud_bud01_repchap6.cfm

Kemfert, C. and Welsch, H. (2000), “Energy-capital-labour substitution and the economic effect of CO2 abatement: evidence for Germany”, Journal of Policy Modelling, 22 (6), p. 641-660.

Layard, R., Nickell, S. and Jackman, R. (1991), *Unemployment: macroeconomic performance and the labour market*, Oxford University Press, Oxford.

Manresa, A. and Sancho, F. (2005), “Implementing a double-dividend: recycling ecotaxes towards lower labour taxes”, Energy Policy, 33, p. 1577-1585.

Minford, P., Stoney, P., Riley, J. and Webb, B. (1994), "An econometric model of Merseyside: validation and policy simulations", Regional Studies, 28, p. 563-575.

Parry, I.W.H. and Bento, A.M. (2000), "Tax deductions, environmental policy, and the 'double dividend' hypothesis", Journal of Environmental Economics and Management, 39, p. 67-96.

Patuelli, P., Nijkamp, P. and Pels, E. (2005), "Environmental tax reform and the double dividend: A meta-analytical performance assessment", Ecological Economics, 55, p. 564-583.

Pench, A. (2001), "Green tax reforms in a computable general equilibrium model for Italy", FEEM Working Paper 3.2001.

Pigou, A. (1938), *The Economics of Welfar*e, Macmillan, London.

Scrimgeour, F.G., Oxley, L. and Fatai, K.(2005), "Reducing carbon emissions? The relative effectiveness of different types of environmental tax: the case of New Zealand", Environmental Modelling and Software, 20, p. 1439-1448.

Semboja, H.H.H. (1994), "The impacts of energy taxes on the Kenyan economy: a CGE analysis", Energy Economics, 16(3), p. 205-215.

Takeda, S. (2006), "The double dividend from carbon regulations in Japan", Journal of the Japanese and International Economies, In Press.

Varma, A. (2003), "UK's climate change levy: cost effectiveness, competitiveness and environmental impacts", Energy Policy, 31, p. 51-61.

Wissema, W. and Dellink, R. (2006), "AGE analysis of the impact of a carbon energy tax on the Irish economy", Ecological Economics, 61(4), p. 671-683.

Table 1: Levy rates for Climate Change Levy 2001/2

Energy source	*Levy rate (pence/kWh)*
Electricity	0.43
Gas	0.15
Coal	0.15
LPG	0.07

Table 2: Aggregate short- and long-run macroeconomic impacts of a reduction in national insurance contributions of 0.3% under alternative labour market specifications, % changes from base year

	Bargaining		Exogenous labour supply		Real wage resistance	
	Short run	Long run	Short run	Long run	Short run	Long run
GDP (income measure)	0.006	0.013	0.000	0.000	0.011	0.060
Investment	0.008	0.013	-0.002	-0.001	0.018	0.059
Exports	0.015	0.024	0.007	0.008	0.022	0.081
Imports	-0.008	-0.010	-0.009	-0.008	-0.007	-0.019
Nominal before-tax real wage	0.005	0.008	0.022	0.021	-0.011	-0.040
Real take-home consumption wage	0.013	0.019	0.026	0.025	0.000	0.000
Consumer price index	-0.008	-0.012	-0.005	-0.003	-0.011	-0.040
Total employment	0.009	0.014	0.000	0.000	0.018	0.061
Unemployment rate (%)	-0.114	-0.171	0.000	0.000	-0.223	-0.762
Total population	0.000	0.000	0.000	0.000	0.000	0.000

Figure 1: The GE impact of a decrease in labour taxation on the labour market

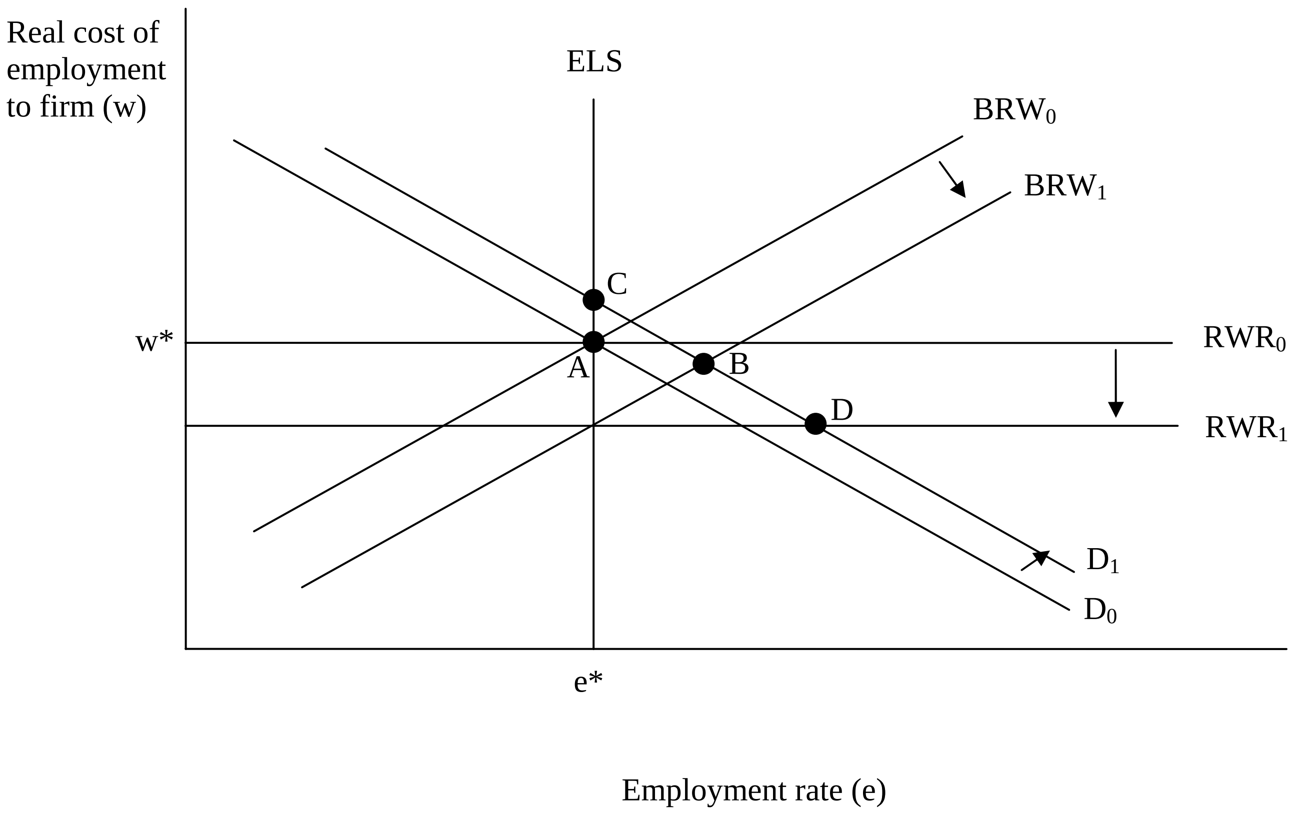


Figure 2: Production hierarchy of each sector i in the 25 sector/commodity UKENVI framework

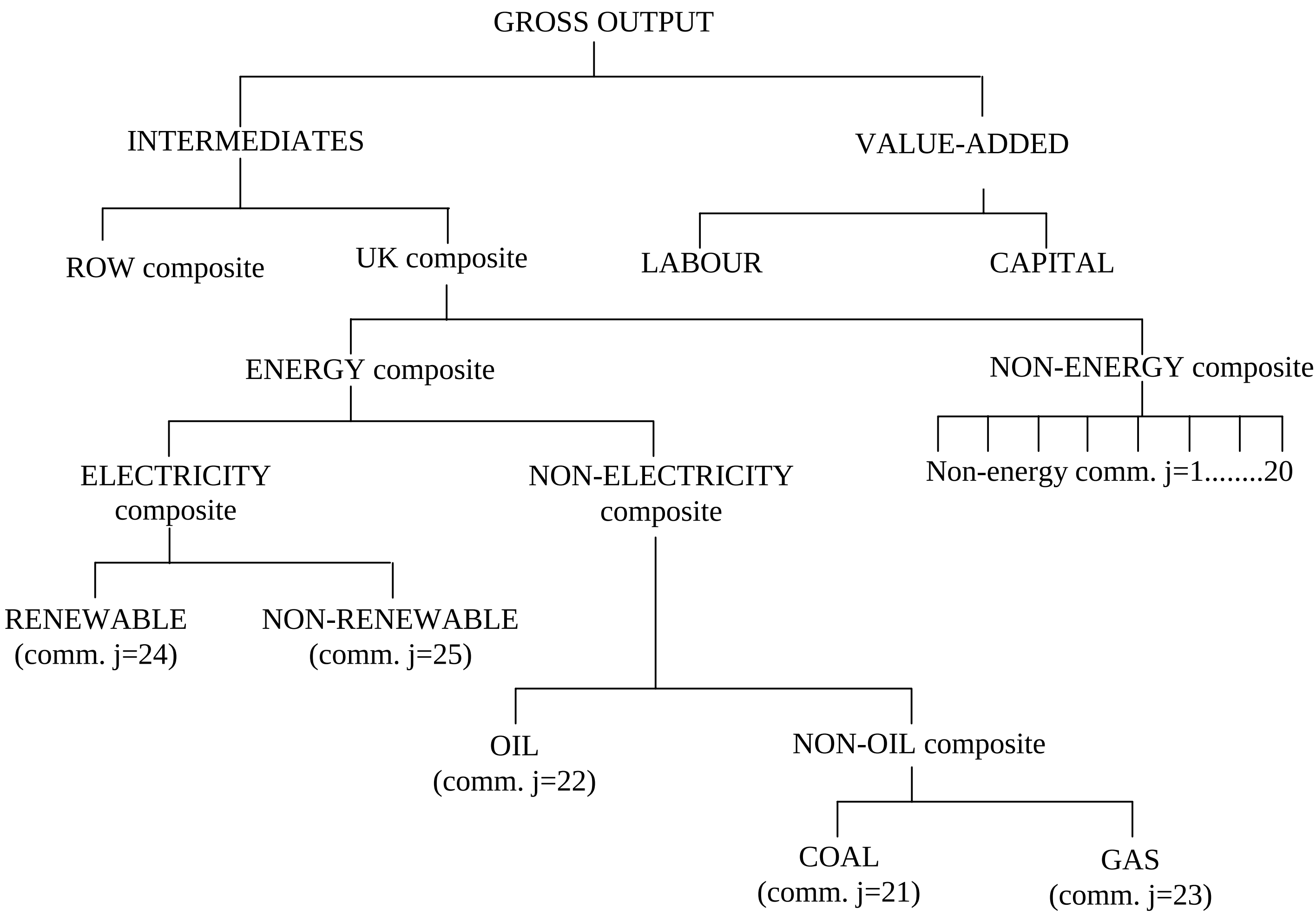


Figure 3: The time path of absolute GDP impact under the alternative labour market specifications

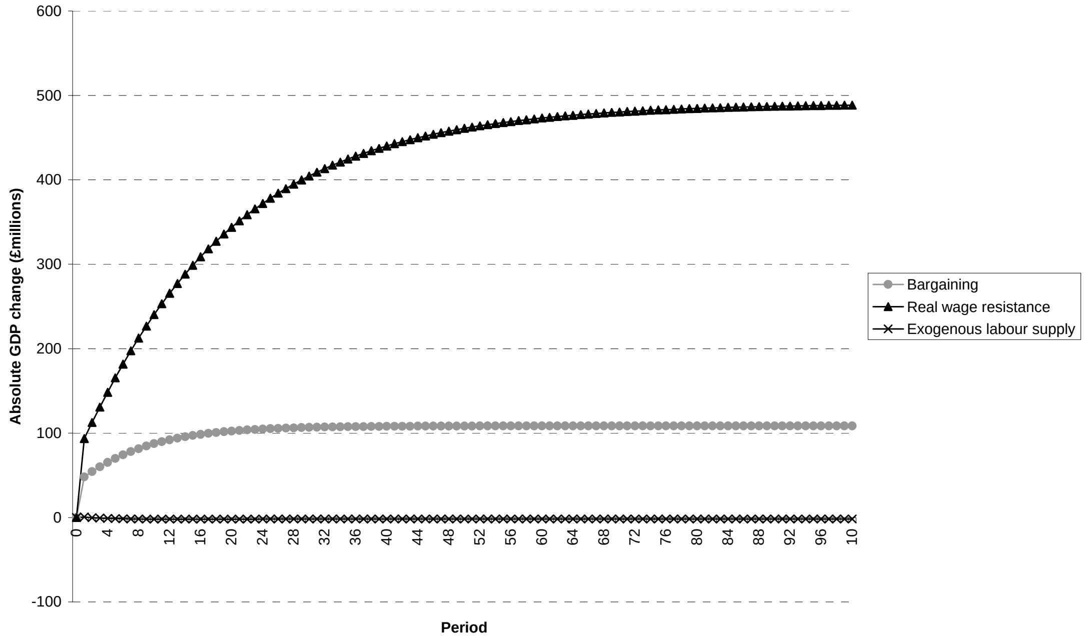


Figure 4: The time path of absolute employment impact under the alternative labour market specifications

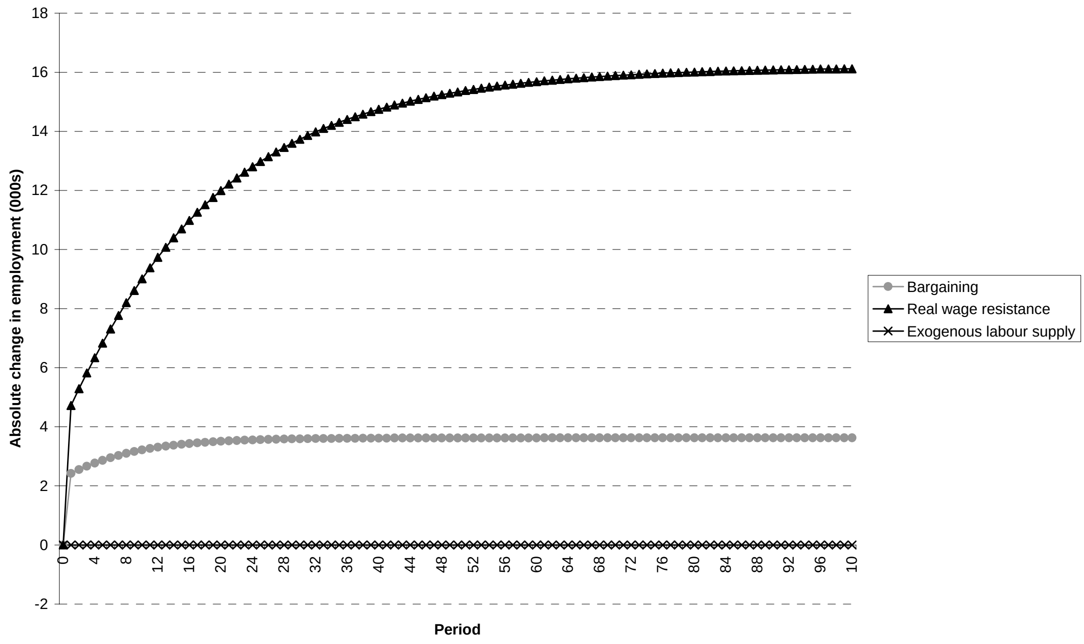
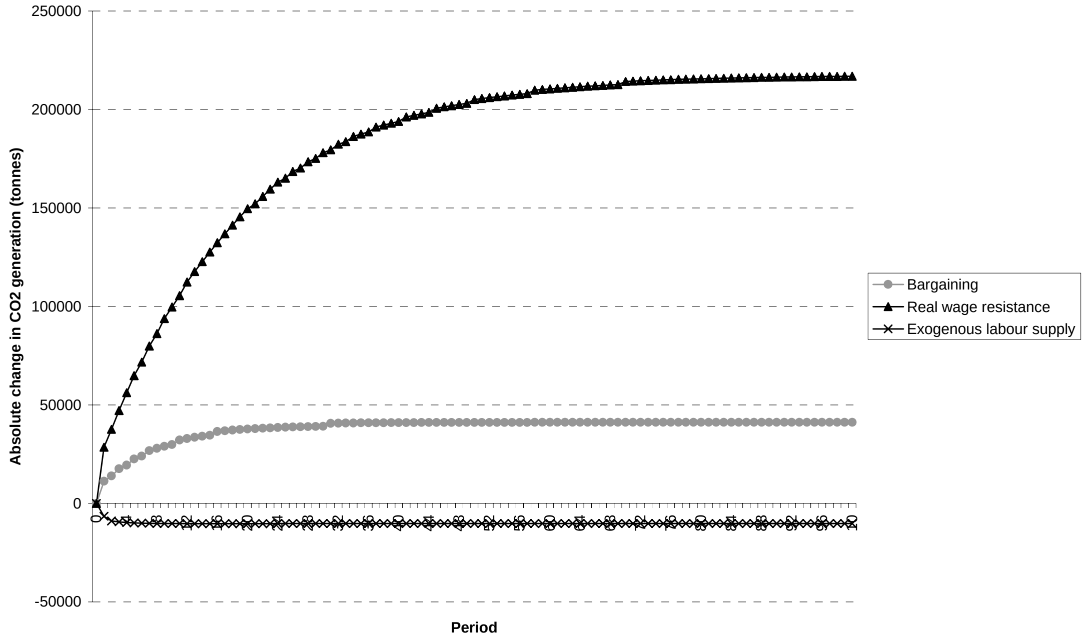


Figure 5: The time path of absolute CO2 emissions under the alternative labour market specifications



Appendix 1: Sectoral aggregation used in UKENVI

Sector	*SIC (92)*
Agriculture, forestry and fishing	1, 2, 5
Other mining and quarrying, including oil and gas extraction	11 to 14
Food and drink	15.1 to 16
Textiles	17.1 to 19.3
Pulp, paper and articles of paper and board	21.1 to 21.2
Glass and glass products, ceramic goods and clay products	26.1 to 26.4
Cement, lime plaster and articles in concrete, plaster and cement and other non-metallic products	26.5 to 26.8
Iron, steel first processing, and casting	27.1 to 27.5
Other metal products	28.1 to 28.7
Other machinery	29.1 to 29.7
Electrical and electronics	30 to 33
Other manufacturing	20, 22, 24.11 to 25.2, 34 to 37
Water	41
Construction	45
Distribution and transport	50 to 63
Communications, finance and business	64.1 to 72 and 74.11 to 74.8
Research and development	73
Public admin and education	75+80
Health and social work	85.1-85.3
Other services	90-95
Coal (Extraction)	10
Oil processing and nuclear refining	23
Gas	40.2 to 40.3
Electricity – renewable	40.1
Electricity - non-renewable	40.1

Appendix 2. A condensed version of UKENVI

(1) Gross Output Price	$pq_i = pq_i(pv_i, pm_i)$
(2) Value Added Price	$pv_i = pv_i(w_n, w_{k,i})$
(3) Intermediate Composite Price	$pm_i = pm_i(pq)$
(4) Wage setting	$w_n = w_n\left(\frac{N}{L}, cpi, t_n\right)$
(5) Labour force	$L = \bar{L}$
(6) Consumer price index	$cpi = \sum_i \theta_i \, pq_i + \sum_i \theta_i^{RUK} \overline{pq}_i^{RUK} + \sum_i \theta_i^{ROW} \overline{pq}_i^{ROW}$
(7) Short-run capital supply	$K_i^s = \bar{K}_i^s$
(8) Long-run capital rental	$w_{k,i} = uck(kpi)$
(9) Capital price index	$kpi = \sum_i \gamma_i \, pq_i + \sum_i \gamma_i^{RUK} \overline{pq}_i^{RUK} + \sum_i \gamma_i^{ROW} \overline{pq}_i^{ROW}$
(10) Labour demand	$N_i^d = N_i^d(V_i, w_n, w_{k,i})$
(11) Capital demand	$K_i^d = K_i^d(V_i, w_n, w_{k,i})$
(12) Labour market clearing	$N^s = \sum_i N_i^d = N$
(13) Capital market clearing	$K_i^s = K_i^d$
(14) Household income	$Y = \Psi_n N w_n (1 - t_n) + \Psi_k \sum_i w_{k,i}(1 - t_k) + \bar{T}$
(15) Commodity demand	$Q_i = C_i + I_i + G_i + X_i + R_i$

(16) Consumption Demand	$C_i = C_i\left(pq_i, \overline{pq}_i^{RUK}, \overline{pq}_i^{ROW}, Y, cpi\right)$
(17) Investment Demand	$I_i = I_i\left(pq_i, \overline{pq}_i^{RUK}, \overline{pq}_i^{ROW}, \sum_i b_{i,j} I_j^d\right)$ $I_j^d = h_j\left(K_j^d - K_j\right)$
(18) Government Demand	$G_i = \overline{G}_i$
(19) Export Demand	$X_i = X_i\left(p_i, \overline{p}_i^{RUK}, \overline{p}_i^{ROW}, \overline{D}^{RUK}, \overline{D}^{ROW}\right)$
(20) Intermediate Demand	$R_{i,j}^d = R_i^d\left(pq_i, pm_j, M_j\right)$ $R_i^d = \sum_j R_{i,j}^d$
(21) Intermediate Composite Demand	$M_i = M_i\left(pv_i, pm_i, Q_i\right)$
(22) Value Added Demand	$V_i = V_i\left(pv_i, pm_i, Q_i\right)$

NOTATION

Activity-Commodities

i, j are, respectively, the activity and commodity subscripts (There are twenty-five of each in UKENVI: see Appendix 1.)

Transactors

RUK = Rest of the UK, ROW = Rest of World

Functions

pm (.), pq(.), pv(.)	CES cost function
k^S(.), w(.)	Factor supply or wage-setting equations
K^d(.), N^d(.), R^d(.)	CES input demand functions
C(.), I(.), X(.)	Armington consumption, investment and export demand functions, homogenous of degree zero in prices and one in quantities
uck	User cost of capital

Variables and parameters

C	consumption
D	exogenous export demand
G	government demand for local goods
I	investment demand for local goods
$\mathbf{I^d}$	investment demand by activity
$\mathbf{K^d, K^S, K}$	capital demand, capital supply and capital employment
L	labour force
M	intermediate composite output
$\mathbf{N^d, N^S, N}$	labour demand, labour supply and labour employment
Q	commodity/activity output
R	intermediate demand
T	nominal transfers from outwith the region
V	value added
X	exports
Y	household nominal income
$\mathbf{b_{ij}}$	elements of capital matrix
cpi, kpi	consumer and capital price indices
d	physical depreciation
h	capital stock adjustment parameter
pm	price intermediate composite
pq	vector of commodity prices
pv	price of value added
$\mathbf{t_n, t_k}$	average direct tax on labour and capital income
u	unemployment rate
$\mathbf{w_n, w_k}$	price of labour to the firm, capital rental
$\mathbf{\Psi}$	share of factor income retained in region

θ	consumption weights
γ	capital weights